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Geometry of River Networks I: Scaling, Fluctuations, and Deviations

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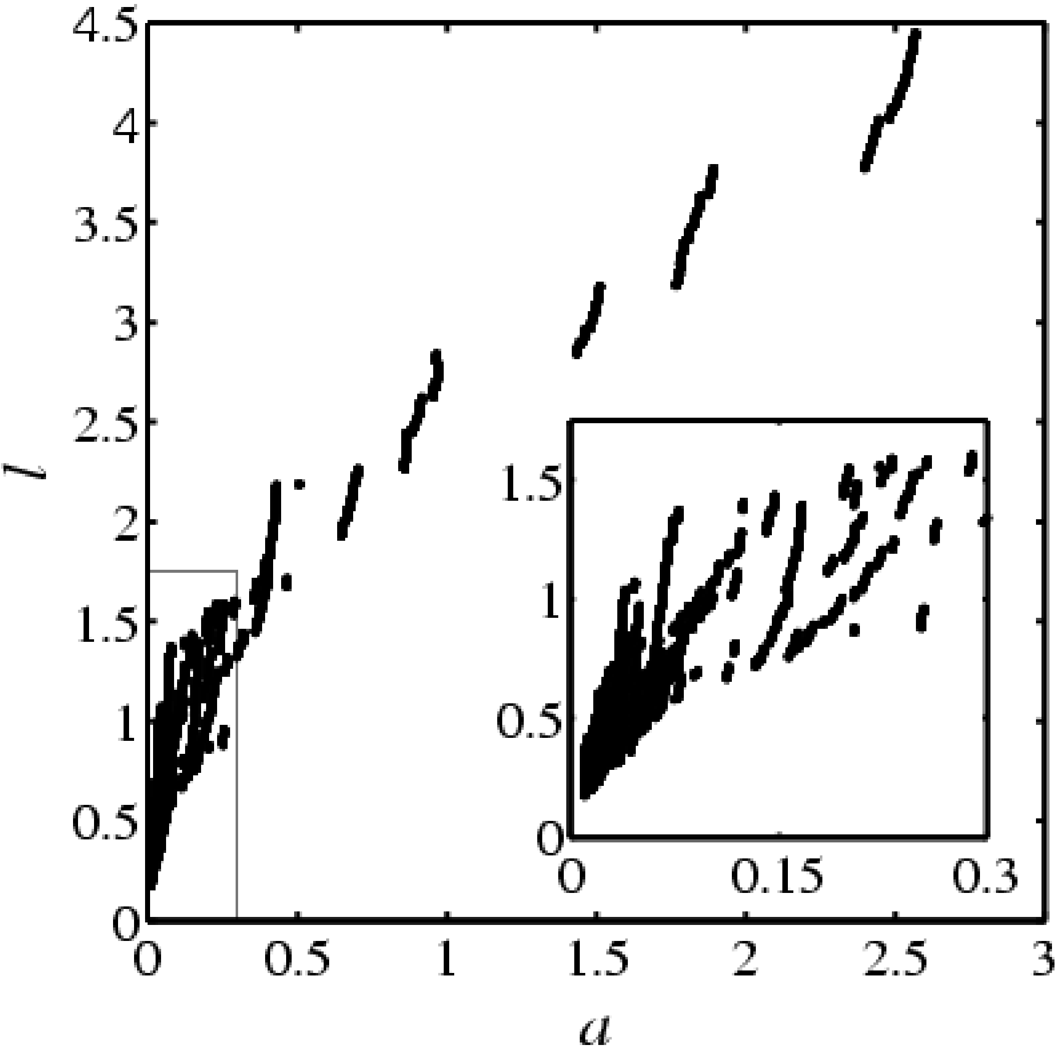
abstract This article is the first in a series of three papers investigating the detailed geometry of river networks. Branching networks are a universal structure employed in the distribution and collection of material. Large-scale river networks mark an important class of two-dimensional branching networks, being not only of intrinsic interest but also a pervasive natural phenomenon. In the description of river network structure, scaling laws are uniformly observed. Reported values of scaling exponents vary suggesting that no unique set of scaling exponents exists. To improve this current understanding of scaling in river networks and to provide a fuller description of branching network structure, here we report a theoretical and empirical study of fluctuations about and deviations from scaling. We examine data for continent-scale river networks such as the Mississippi and the Amazon and draw inspiration from a simple model of directed, random networks. We center our investigations on the scaling of the length of sub-basin's dominant stream with its area, a characterization of basin shape known as Hack's law. We generalize this relationship to a joint probability density and provide observations and explanations of deviations from scaling. We show that fluctuations about scaling are substantial and grow with system size. We find strong deviations from scaling at small scales which can be explained by the existence of linear network structure. At intermediate scales, we find slow drifts in exponent values indicating that scaling is only approximately obeyed and that universality remains indeterminate. At large scales, we observe a breakdown in scaling due to decreasing sample space and correlations with overall basin shape. The extent of approximate scaling is significantly restricted by these deviations and will not be improved by increases in network resolution.



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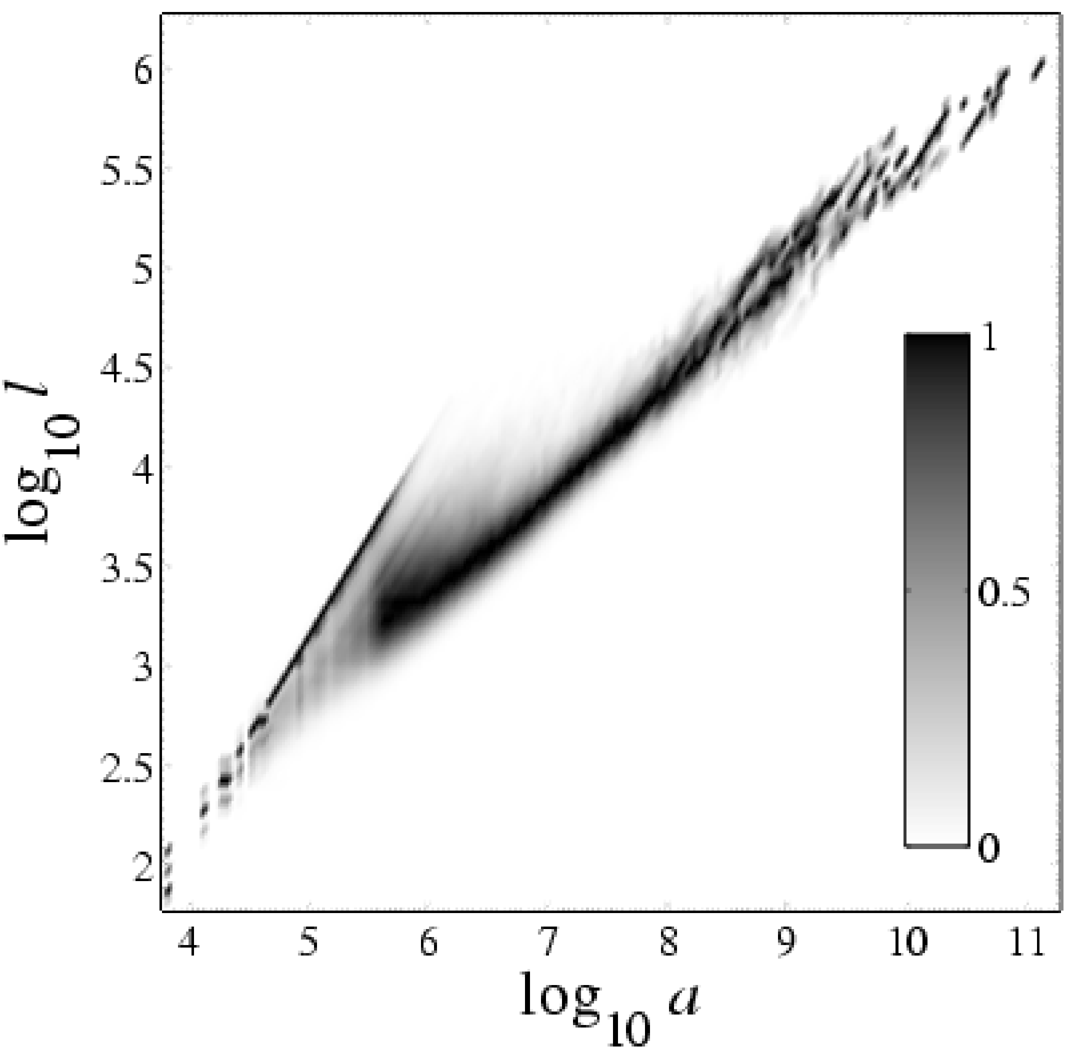

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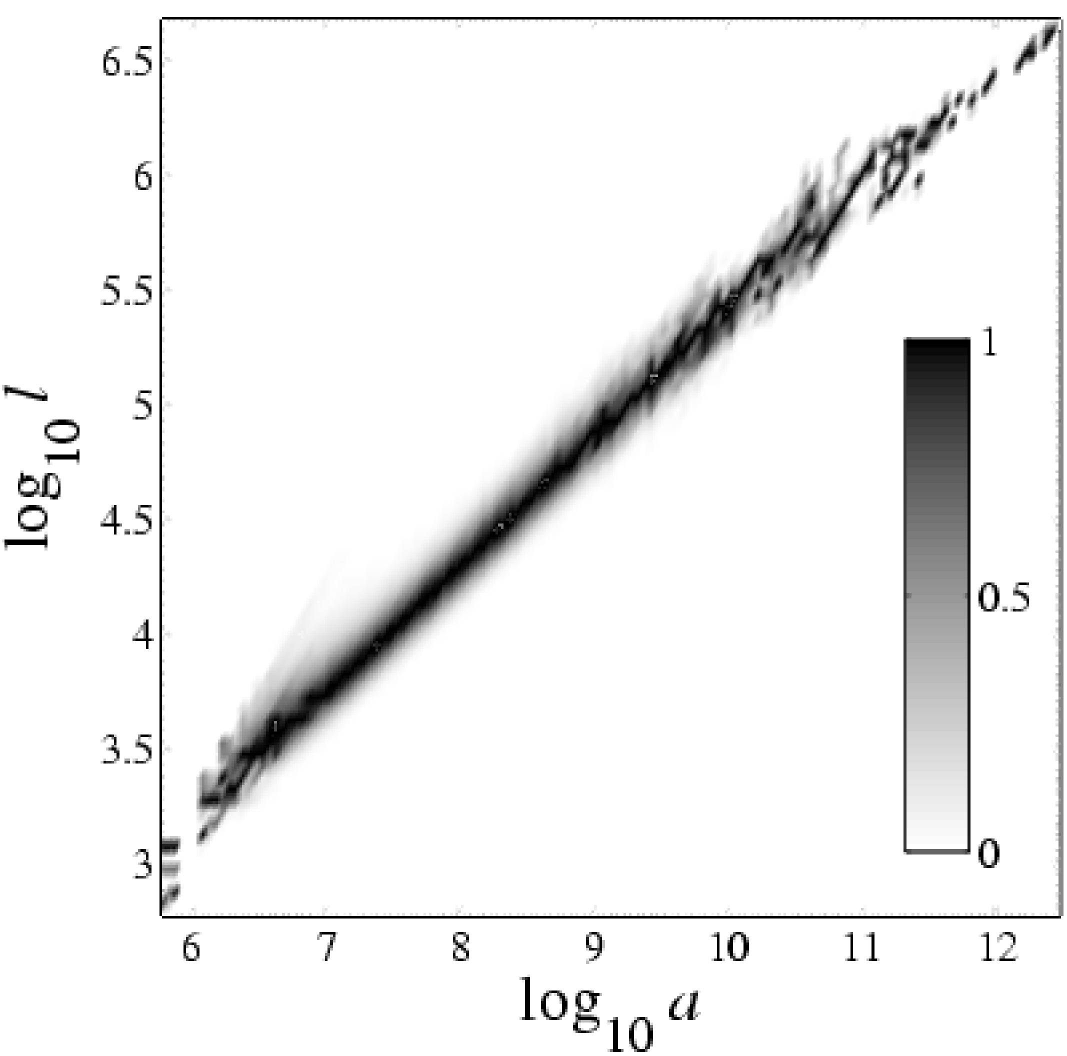

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